



Community Excellence



Operational Excellence



Scientific & Technical Excellence

I D A H O N A T I O N A L L A B O R A T O R Y

FY2020 LAB OVERVIEW

*CHANGING THE WORLD'S
ENERGY FUTURE*

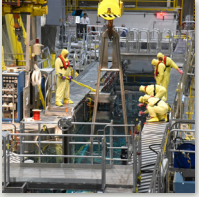


Idaho National Laboratory

Cover captions



INL's K-12 science, technology, engineering, and math (STEM) education and outreach program focuses on developing a skilled, talented, and prepared STEM-literate workforce. Outreach is focused on students, teachers, and the community and strives to instill a STEM mindset, based in a trial-and-error approach, to advance critical thinking. INL's Catherine Riddle leads Cloverdale Elementary School students in a hands-on STEM activity.



INL's Advanced Test Reactor (ATR) is the world's most powerful research reactor and serves as the flagship irradiation facility in the United States, able to support a wide range of experiments for multiple customers simultaneously, including DOE nuclear research and development programs, the U.S. Navy, and university and industry research partners. Operations staff at the ATR are responsible for ensuring the safe and reliable operation and performance of the reactor, including fuel inspections at the ATR canal, as shown here.



INL continues to develop electrometallurgical and hybrid zirconium removal prior to extraction (ZIRCEX) in uranium recovery processes. Head-end processes prepare used nuclear fuel for component separation, and are the first step in the process of recovering highly enriched uranium for down-blending. ZIRCEX is a dry head-end process for removing zirconium or aluminum cladding from used nuclear fuel. INL's pilot plant is a one-fourth scale ZIRCEX facility that will demonstrate process control at maximal reaction rates. Pilot-scale testing will also determine the best equipment designs for the full-scale process.



"Idaho National Laboratory (INL) plays an important role in helping our nation resolve its major energy and security challenges."

Every day, our talented staff work to produce innovative nuclear energy solutions and other clean energy sources, while protecting the U.S. power grid and vital systems from man-made and natural threats.

Completion of our clean energy and national security missions requires vision and a plan. This 2020 Laboratory Overview outlines how we intend to accomplish these objectives in service to our fellow citizens.

As we prepare for the future, it is worth noting that 2019 was an excellent year at the Laboratory, another brick in the research and development foundation upon which we will continue to build success.

In 2019, INL celebrated its 70th anniversary. As part of that celebration, the Laboratory hosted the “Energizing the Modern Age” symposium.

This event brought together leading minds from science, business, communications, academia, and conservation and will serve as a starting point for an important and ongoing conversation.

INL was designated the nation’s National Reactor Innovation Center (NRIC), placing the Laboratory at the forefront of working with industry to design, develop, and demonstrate the advanced reactor systems needed to power our future.

INL opened the Cybercore Integration Center and Collaborative Computing Center. These state-owned facilities, which are being leased to the Laboratory, enhance our core missions while facilitating partnerships with Idaho’s universities to train and educate students.

2020 has brought with it significant and unexpected challenges, but I anticipate another excellent year at INL filled with notable achievements.

I say that because INL continues to expand its leadership across the nation’s science and technology initiatives.

With world-class staff working at state-of-the-art facilities on our 890-square-mile Site and in Idaho Falls, INL is uniquely capable of resolving specific clean energy and national security challenges.

We stand prepared to demonstrate solutions, especially regarding advanced reactors. For a long time, we’ve talked about next-generation nuclear reactors. Now, implementing the vision laid out by the U.S. Department of Energy (DOE) and Congress, it’s time to start building and demonstrating advanced reactors.

Through NRIC, INL will work with our industry partners DOE to enable the life cycle of safe, affordable, and reliable nuclear reactor technologies.

We will continue groundbreaking research and development on integrated energy systems, making the current American nuclear reactor fleet and future energy systems more economically feasible while reducing carbon emissions.

In 2020, INL will continue laying the groundwork for a Versatile Test Reactor (VTR), which will allow U.S. scientists and companies access to vital testing currently unavailable in our country.

We will work with the U.S. Department of Defense and our industry partners on microreactor research, a potential game-changer for troops serving abroad, remote industrial operations, and small, isolated communities across the nation.

We will continue to partner with industry and government to develop programs and initiatives vital to U.S. national security while protecting America’s power grid and other critical infrastructure from man-made and natural threats.

We will continue to push forward on our work with the National Aeronautics and Space Administration, biofuels, electric-vehicle battery research, advanced materials and manufacturing, and so much more. And we will continue to do this in 2021 while embracing transparency and with the safety and well-being of our staff foremost in mind.

The following pages highlight some of INL’s notable impacts from FY 19 and provide an overview of how we will accomplish our objectives, implement our vision, and fulfill our obligations to the American taxpayer going forward.



Dr. Mark Peters
Director, Idaho National Laboratory

INL OVERVIEW

As the U.S. leader for advanced nuclear energy research, development, and demonstration (RD&D), INL leverages its talented workforce, world-class test bed facilities, and unique infrastructure to discover, demonstrate, and secure innovative nuclear energy solutions, other low-carbon energy options, and critical infrastructure. INL combines basic research, applied science and engineering, and problem-solving to pursue its vision to change the world's energy future and secure our nation's critical infrastructure.

INL research enables innovative, low-carbon energy systems that will integrate baseload power from nuclear and other sources with intermittent renewables, while also repurposing heat and electricity from existing reactors for direct use and to support industrial processes. Achieving this integrated low-carbon energy future requires innovation across a spectrum of

technologies. Leading RD&D for advanced reactor technologies and improved fuel cycle elements will sustain the existing fleet and expand future deployment of nuclear energy. Advances in energy generation, delivery, and storage technologies will improve systems integration. Addressing materials and manufacturing challenges unique to extreme environments will yield new materials and processes for nuclear and other energy systems, as well as aerospace, transportation, and defense systems. Confronting significant national security challenges in critical infrastructure protection, cybersecurity, and nuclear nonproliferation will secure the cyber-physical infrastructure essential to energy and defense systems. INL's efforts combine to ensure that in the short-term our nation's fleet of nuclear reactors remains safe and effective, while developing and deploying

the next generation of reactors, supported by an advanced fuel cycle, and integrated with other renewable sources of energy and industrial manufacturing processes. Work in advanced materials and manufacturing supports technological advances while cyber-physical security systems provide essential protections.

INL's multidisciplinary approach to RD&D leverages robust partnerships with federal entities, other national laboratories, international organizations, universities, and private industry to accelerate research breakthroughs to deployment. Together, we will achieve low-carbon integrated energy systems, changing the world's energy future and securing our nation's critical infrastructure.

INL VALUES

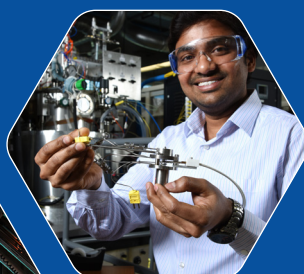
Excellence, Inclusivity,
Integrity, Ownership,
Teamwork, Safety

INL VISION

INL will change the world's energy future and secure our critical infrastructure.

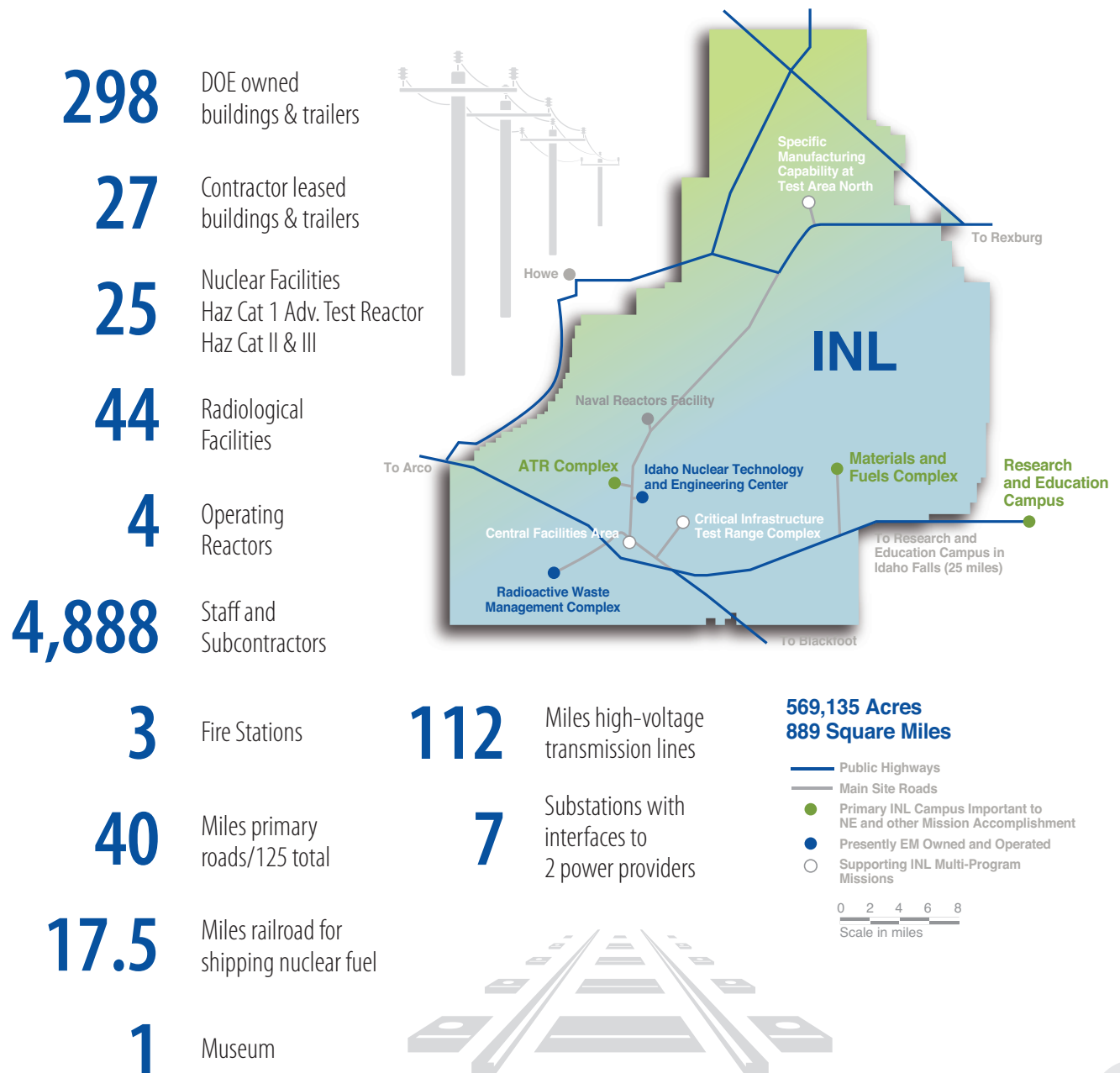
INL MISSION

Discover, demonstrate,
and secure innovative
nuclear energy solutions,
clean energy options
and critical infrastructure.





INL is the Nation's Nuclear Laboratory, Leveraging Multiprogram Capabilities to Address Energy and Security Challenges at Scale



All metrics presented in this documents are for fiscal year 2019.

FY 19 LAB AT A GLANCE

Facts

- **Location:** Idaho Falls, Idaho
- **Type:** Multiprogram Laboratory
- **Contractor:** Battelle Energy Alliance (BEA)
- **Responsible Site Office:** DOE-ID

Physical Assets

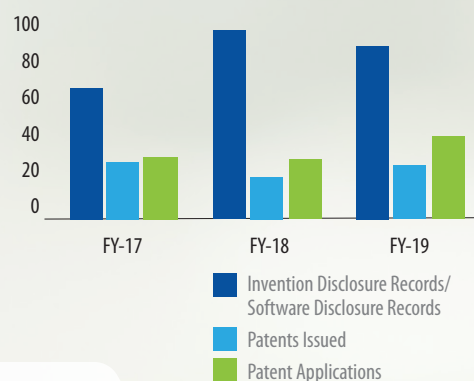
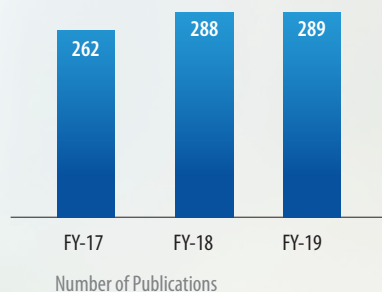
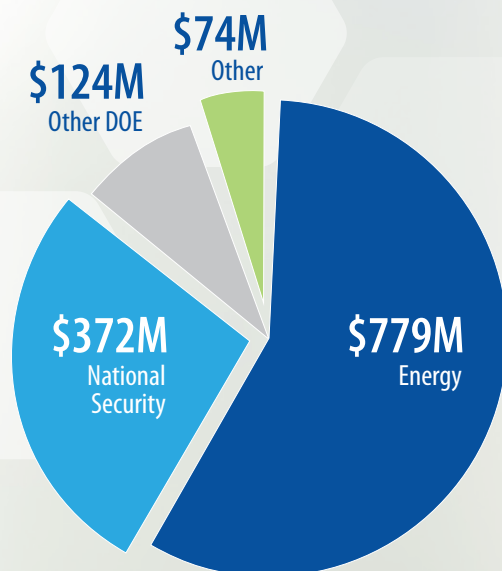
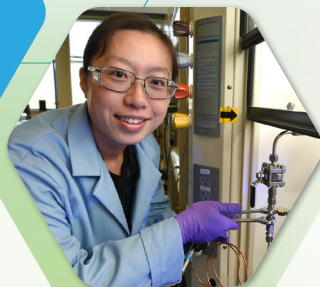
- 569,180 acres and 540 real property assets (DOE owned assets that are operating or standby)
- 2.3 million gross square feet (GSF) in owned operating buildings
- 9,609 GSF in three excess facilities
- \$5.6 billion in replacement plant value (DOE owned assets)
- 20,363 GSF in three excess facilities
- 1 million GSF in leased facilities

Funding by Source (\$M)

- FY 19 Lab Operating Cost: \$1,349M
- Total DOE/NSNSA Costs: \$980M
- SPP (Non-DOE/Non-DHS): \$300M
- CRADA: \$9M
- Total DHS Costs: \$61M

Human Capital

- 4,888 full-time equivalent employees
- 36 joint appointments
- 68 postdoctoral researchers
- 20 high school interns
- 265 undergraduate interns
- 200 graduate interns
- 691 facility users
- 12 visiting scientists

INL in
FY 19

8

Active distinguished
postdocs

13

Technology
Commercialization
Fund projects

117

Active Laboratory Directed
Research & Development
(LDRD) projects

19

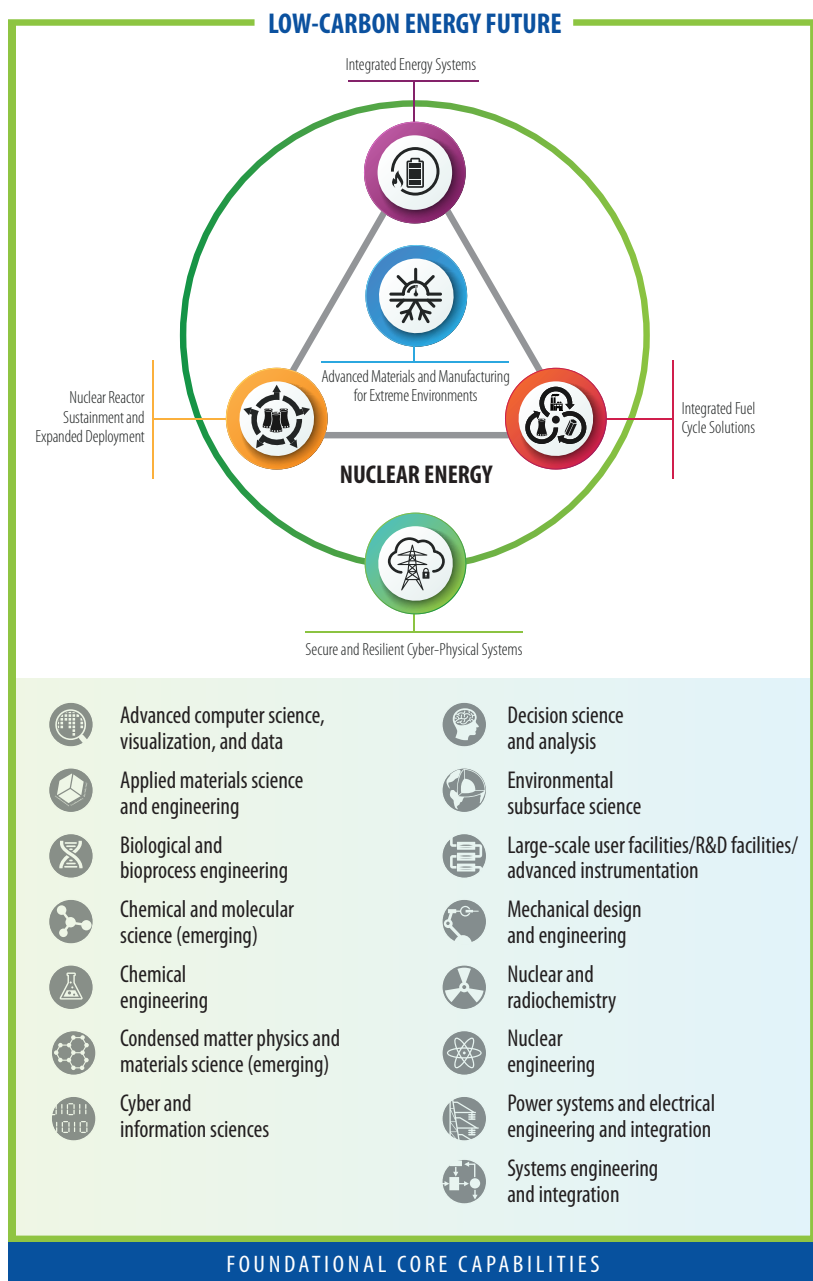
Postdocs transitioned
to staffNew hires from
42 states
21 countries

INL'S STRATEGIC S&T INITIATIVES ADVANCE ENERGY AND SECURITY GOALS FOR THE NATION

INL leverages its foundational core capabilities to advance innovative RD&D across five science and technology (S&T) initiatives: nuclear reactor sustainment and deployment; integrated fuel cycle solutions; advanced materials and manufacturing for extreme environments; integrated energy systems; and secure and resilient cyber-physical systems. These five S&T initiatives contribute to changing the world's energy future and securing our nation's critical infrastructure.

These initiatives build on INL's RD&D leadership in nuclear energy to advance a vision of a low-carbon energy future that fully realizes the game-changing potential of nuclear energy. The low-carbon energy systems of the future will integrate the baseload power of nuclear energy, geothermal, and other baseload sources, with intermittent renewables, while repurposing heat and electricity from existing reactors for direct use and to support industrial processes, such as hydrogen generation. These integrated energy systems will require advanced reactor technologies and improved fuel cycle elements to sustain the existing fleet and expand deployment of nuclear energy.

As the nation's nuclear energy laboratory, INL is uniquely prepared to lead the development of the integrated low-carbon energy systems of the future. Developing these integrated energy systems requires significant R&D advances in grid integration, energy storage, and hydrogen production, coupled with systems engineering innovations. Both integrated energy systems and advanced nuclear systems require disruptive innovations in advanced materials and manufacturing for extreme environments and inherently resilient and secure cyber-physical infrastructure. With nuclear energy as the foundation, INL's S&T initiatives are designed



to support and accelerate innovation across all five initiatives simultaneously to advance the integrated energy systems key to a low-carbon energy future.

DOE designates a total of 24 core capabilities shared across DOE's science and applied energy laboratories. INL focuses on 13 core capabilities

and two emerging core capabilities to achieve its mission. These core capabilities represent a comprehensive science and engineering skill set that extends across a continuum, connecting basic and applied research to develop, test, demonstrate, and validate technologies at scale, speeding deployment and reducing risks.

NUCLEAR REACTOR SUSTAINMENT AND EXPANDED DEPLOYMENT

The baseload power provided by nuclear reactors is essential to the world's integrated low-carbon energy future.

Today, 10% of the world's electricity comes from 450 power reactors, and many of those are aging. To meet the growing demand for sustainable energy, nuclear power generation must triple by 2050 to provide 25% of a clean and reliable low-carbon mix. Because the addition of new nuclear energy systems will take time, it is also essential to sustain the current fleet to facilitate continued safe and economical operations in the interim.

INL uses its unique combination of world-class RD&D experience, infrastructure assets, and partnership relationships to address the most difficult technical and operational challenges of the existing fleet, advanced fuels, and advanced reactor design and demonstration to sustain the existing fleet and expand deployment of nuclear energy in the future.

INL leads in creating and defining the next phase of global nuclear energy by driving technological innovations and operational advances through proof of concept, proof of performance, and proof of operations. These advances will further U.S. competitiveness and leadership in both the existing and the developing nuclear technology markets.

INL's nuclear reactor sustainment and expanded deployment S&T initiative advances foundational science, at scale demonstrations, technology validation, and strategic partnerships to:

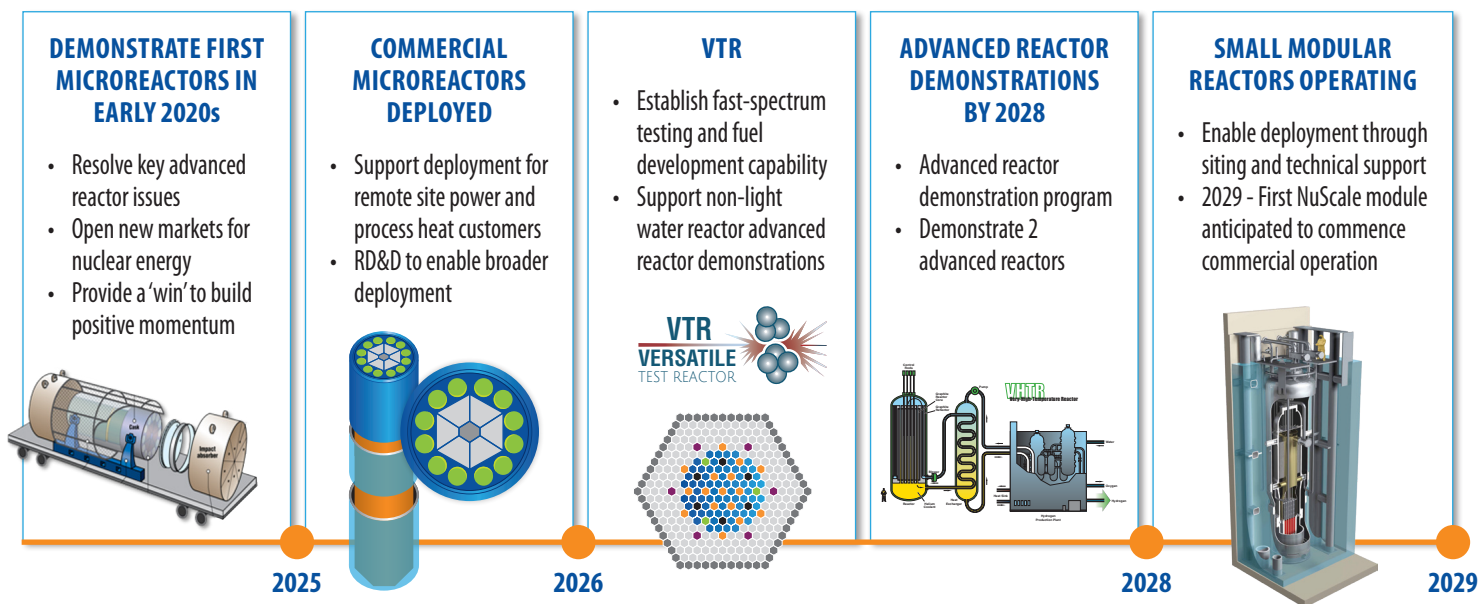
1. strengthen the domestic commercial nuclear energy enterprise,
2. enable U.S. technological leadership in global nuclear energy markets, and
3. expand and deploy national nuclear energy strategic infrastructures.



INL works with industry on control room modernization efforts



INL partnered with Westinghouse to fabricate the first ever accident tolerant U_3Si_2 fuel pellets inserted into a commercial reactor



INL anticipates deploying new demonstration and test reactors regularly over the next ten years





Jokisaari's LDRD will further INL's excellence in basic sciences of irradiation effects on materials and support the development and deployment of next-generation reactors worldwide

LDRD SUCCESS STORY

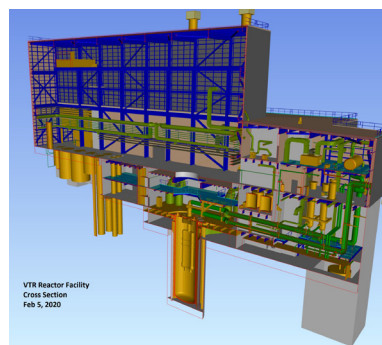
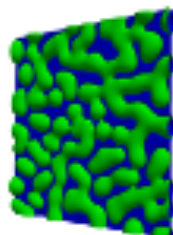
Andrea Jokisaari combines computational modeling and simulation with experimental irradiation and characterization to understand and predict irradiation damage in uranium. She both advances fundamental scientific understanding of materials mechanisms and develops tools that can be used to predict the behavior of metallic fuels for a variety of reactors and conditions.



FY 19 IMPACT

BISON, a simulation tool based on INL's user-developed and open-source code Multiphysics Object-oriented Simulation Environment (MOOSE), was developed to predict the behavior of nuclear fuels and materials undergoing irradiation for nuclear reactors under normal operating and accident conditions. Industry interest and relevance of BISON and the complementary Marmot platform was demonstrated by on-site training and user support at Westinghouse, General Atomics, Kairos Power, the Electric Power Research Institute, and the Nuclear Regulatory Commission. BISON predictions of U_3Si_2 accident tolerant fuel fuel swelling and fission gas release behavior were significantly improved by parameterization from Marmot lower length-scale simulations, a demonstration that such parameters can be determined quickly for new fuels using lower length scale simulations. Kairos Power announced to the Nuclear Regulatory Commission their intent to use BISON for the design and licensing of their tristructural isotropic (TRISO) particle fuel technology.

The Marmot simulation of accident tolerant fuel gas bubbles on a grain boundary provides more accurate information about core temperatures helping engineers make nuclear reactors safer and more reliable



VTR conceptual design, developed using state-of-the-art digital engineering tools

INL manages VTR for NE

VTR will be a 300 MWth pool-type sodium-cooled reactor fueled by a ternary metallic (uranium-plutonium-zirconium) alloy. VTR will provide a high fast-neutron flux for accelerated testing. The reactor core is designed to house next-generation test vehicles and experimental capabilities. When completed, VTR will be used to test fuels, materials, instrumentation, and sensors in the fast-neutron spectrum, which will fill a major gap in the U.S. nuclear energy RD&D infrastructure. When integrated with the capabilities of INL's existing RD&D infrastructure, VTR will enable the U.S. to regain and sustain leadership in advanced reactor technologies.

The VTR team includes five other national laboratories, 20 universities, and multiple private companies. Mission need for VTR was approved in February 2019. In August 2020, BEA initiated contract negotiations with a team led by Bechtel National Inc., including TerraPower and GE Hitachi Nuclear Energy, to support the design and build phase of the VTR. In September 2020, DOE announced that it had approved Critical Decision 1, known as "Approve Alternative Selection and Cost Range," the second step in the formal process DOE uses to review and manage research infrastructure projects. The target date for VTR operations is 2026.

INTEGRATED FUEL CYCLE SOLUTIONS

Integrated fuel cycle solutions are necessary for sustaining and expanding nuclear energy in the future. Redefining the nuclear fuel cycle, with an emphasis on cost-effectiveness and waste minimization, is essential to addressing the needs of an aging fleet and developing the next generation of reactors to sustain and expand nuclear energy deployment. INL's integrated fuel cycle solutions S&T initiative supports the safe, secure, and economical management of nuclear fuel from inception to disposition. To enable sustained and expanded nuclear energy through disruptive technology approaches, INL will develop the S&T and infrastructure to support:

1. availability of special nuclear material (SNM),
2. management of radiological waste materials and legacy fuels,
3. reduction in proliferation risk, and
4. RD&D test beds.

Transition to a HALEU fuel Cycle

The current U.S. nuclear fuel supply infrastructure is based on low enriched uranium (LEU) (i.e., less than 5% enrichment). Most of the advanced reactors of the future will require fuel with uranium that is enriched in U-235 in the 5–19.75% range and is commonly referred to as high-assay low-enriched uranium (HALEU). This transition necessitates a shift from a LEU to a HALEU fuel cycle infrastructure, but today the United States lacks domestic infrastructure and enrichment capacity to produce HALEU for the next generation of advanced reactor fuels.

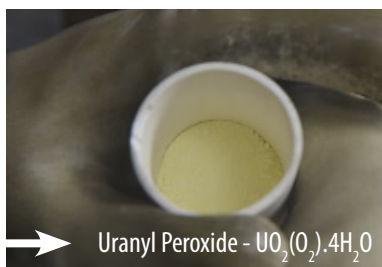
INL is leading DOE efforts to support the development and deployment of the U.S. HALEU fuel cycle infrastructure. DOE sources of HALEU can bridge the initial gap between supply and demand but require further purification to meet fuel fabrication specifications. INL researchers have successfully completed the first experimental campaign to purify down-blended metal HALEU fuel originating from Experimental Breeder Reactor II (EBR-II) driver fuel. The purified HALEU was successfully produced in oxide forms suitable for use as feed stock for advanced reactor fuel fabrication.



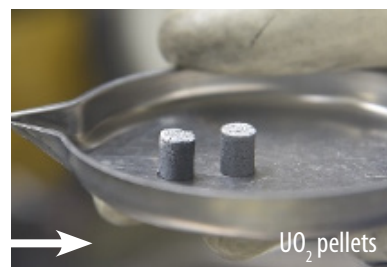
By developing strategies to recycle spent EBR-II fuel into HALEU, with a goal of reprocessing all of the fuel by 2028, the integrated fuel cycle solutions S&T initiative supports the advanced reactor developers who need HALEU fuel and helps INL fulfill its agreements with the State of Idaho



U metal regulus



Uranyl Peroxide - $\text{UO}_2(\text{O}_2) \cdot 4\text{H}_2\text{O}$



UO_2 pellets

INL researchers demonstrated the conversion and purification of EBR-II HALEU material from metallic to oxide





Lyon samples mixer-settlers in the laboratory-scale uranium polishing process

LDRD SUCCESS STORY

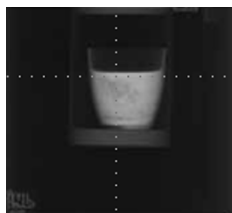
Kevin Lyon is developing a modeling framework for advanced chemical separation processes relevant to the nuclear fuel cycle. This work not only contributed to the integrated fuel cycle solutions S&T initiative, but also contributed to Lyon's Ph.D. dissertation with the University of Idaho. Results from this LDRD have been leveraged in research programs across INL's directorates including HALEU polishing, nuclear nonproliferation, and the Critical Materials Institute.



FY 19 IMPACT

Developing a fuel cycle with inherent process transparency can reduce the risk of nuclear proliferation, so INL focuses on developing fuel cycle technologies that incorporate safeguards by design for the effective and efficient monitoring and verification of nuclear materials throughout the fuel cycle. In FY 19, INL supported proliferation-risk reduction in the integrated fuel cycle through programs that advance material disposition capabilities, including demonstration of direct chemical and physical immobilization options for used nuclear fuel (UNF).

INL conducted proof of concept for immobilization technology demonstrating a viable method to render used fuel unusable increasing proliferation resistance



In FY 19 Moran executed the Leatherman Peak campaign, hosting 10 collaborative partner agencies and allowing testing of 14 collection technologies

Advanced Test Beds

INL leads the Nuclear Chemistry & Reprocessing area for DOE's National Nuclear Security Administration Nonproliferation Stewardship Program. INL takes advantage of existing capabilities to configure flexible R&D test bed facilities that couple the design of front and back-end fuel cycle processes with new safeguards and security concepts. These facilities enable the RD&D of real-time instrumentation tools that support safeguards, and physical and cybersecurity by design concepts. Advanced test beds also allow INL to develop unique capabilities to address DOE legacy issues related to orphan SNM and to establish leadership in advanced reactor development areas including small modular reactors, microreactors, liquid fuel reactors, and TRISO-fuel development.

INL stewards facilities to engage and train the next generation of fuel cycle and nonproliferation experts with a goal of developing and deploying nuclear fuel cycle processing test beds from radiological to glovebox to hot cell facilities. INL's UNF testing facility provides an integrated civilian nuclear fuel cycle test bed capability for the nation including hot cell facilities, configurable campaigns, spent fuel operations, fuel fabrication facilities, and irradiation and post-irradiation examination facilities.

ADVANCED MATERIALS AND MANUFACTURING FOR EXTREME ENVIRONMENTS

Nuclear, aerospace, transportation, defense systems, and other energy systems expose components to a variety of extreme or harsh environments, including high-radiation fields, temperature extremes, corrosive species, chemical containment, dynamic loading, mechanical impact, and both vacuum and high-pressure atmospheres. Advanced materials and manufacturing are needed to improve technologies deployed under these extreme conditions. INL's advanced materials and manufacturing for extreme environments S&T initiative accelerates discoveries and advances in materials for extreme environments, instrumentation, and energy technologies through adaptation, analysis, development, and integration of new or novel techniques.

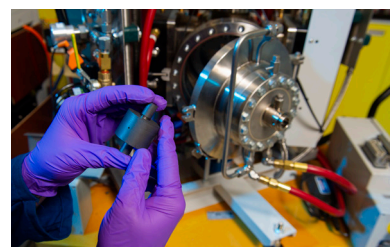
Process-informed design departs from traditional approaches by leveraging scientific understanding of the influence of any given manufacturing process to design materials and components with targeted microstructures and performance characteristics. To advance the goals of the initiative, INL focuses on process-informed design for targeted performance

and application-driven engineered materials and components within three interconnected focus areas:

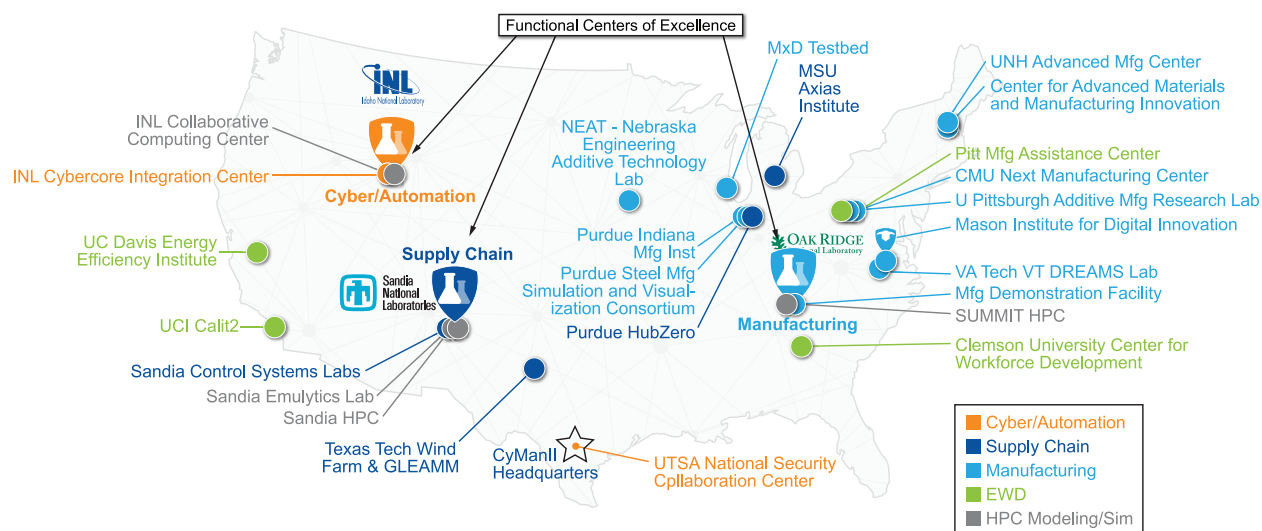
1. process discovery and development,
2. secure digital design and manufacturing, and
3. intensification and scale-up.



INL is advancing towards demonstration of a rolling electric field assisted sintering device with high throughput and energy efficiency and the world's largest direct current electric field sintering press



INL's compact and portable micro-spark plasma sintering (SPS) unit enables in situ X-ray observation and characterization of SPS processing at length scales from micron to millimeter



In May 2020 DOE Selected the University of Texas – San Antonio to lead the Cybersecurity Manufacturing Innovation Institute (CyManII) partnered with Idaho, Oak Ridge and Sandia National Laboratories. CyManII is a public-private consortium to bolster U.S. manufacturing competitiveness, energy efficiency, and innovation. CyManII will focus on early-stage R&D to advance cybersecurity in energy-efficient manufacturing.





The micro-SPS will be used by many projects to develop process-informed science data using X-ray neutrons

LDRD SUCCESS STORY

To develop new hardened ceramic materials for defense systems, Joshua Kane used a newly developed micro-SPS, created for beam-line experiments. Kane developed this system to enable in situ measurement of the sintering kinetics and plastic deformation of novel materials using X-ray interrogation.



FY 19 IMPACT

INL is using innovative additive manufacturing for Transient Reactor Test Facility (TREAT) research. The 3D printed interior of the test capsule goes inside a safety-rated and certified exterior. This approach minimizes the time and money it takes to run an experiment significantly reducing hurdles to innovation. 3D printing and the splitting of the test assembly into two parts cut the cost to run a set of TREAT experiments at least in half and by as much as a factor of 10, saving hundreds of thousands of dollars. INL has successfully deployed this additive manufacturing approach in a test campaign, with more experiments planned.



Components for the first water environment test capsules to be used in TREAT were created with additive manufacturing, allowing for complex geometries specially designed for each test

Collaborating in Pursuit of Disruptive Innovations

The advanced materials and manufacturing for extreme environments S&T initiative is a catalyst for coordination, collaboration, and investment across the Laboratory to meet mission needs. Researchers working on this initiative strive to increase the performance and economic competitiveness of materials used in extreme environments and to establish INL as a leader in process innovation and intensification. To do this, INL will address the nexus of material development, component fabrication, and qualification, from feedstock material through product validation.

With the goal of using highly controlled advanced manufacturing techniques to bring new material systems to market, INL researchers will 1) control and evaluate nuclear, chemical, microstructural, and physical properties; 2) reduce or tailor residual stress, especially in complex geometries; 3) develop functionally graded materials targeted at eliminating dissimilar metal welds in the joining process; and 4) increase the instrumentation, control, and monitoring of advanced fabrication methods, with the potential to systematically control and manipulate material composition and microstructure down to the atomic level.



Continuous
Composites

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POWDERMET
MAKING MATERIALS DO MORE

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GENERAL GRAPHENE



THERMAL TECHNOLOGY LLC
HIGH TEMPERATURE EXPERTS

INTEGRATED ENERGY SYSTEMS

The integrated low-carbon energy systems of the future integrate diverse energy generation systems such as nuclear, geothermal, and other baseload sources, with intermittent renewables. From those energy generation sources, heat and electricity have traditional direct uses and the potential to support industrial processes, such as hydrogen production. To realize an optimized energy future, new integrated approaches to energy generation, storage, distribution, and use are needed.

Nuclear energy is a proven low-emission option that can consistently meet electricity demands, and its potential value extends far beyond electricity generation. Without leveraging the full benefits of nuclear energy, the low-carbon energy systems of the future will unnecessarily operate with inefficiencies and will undervalue some methods and products of energy generation,

delivery, storage, and use. To capitalize on the opportunities beyond baseload electricity generation and to expand the market for nuclear energy, INL's integrated energy systems S&T initiative leverages INL's core capabilities to develop and demonstrate multigeneration energy systems that, by incorporating nuclear energy with other forms of electricity generation, provide grid reliability, resilience, affordability, and new products.

The Laboratory's expertise in nuclear energy provides the basis to efficiently capture, distribute, and store nuclear-generated thermal energy for power generation or direct thermal-energy use. The integrated energy systems S&T initiative works to pave the way for eventual systems adoption by commercial producers and consumers through at-scale demonstration to make low-emission energy products economically

viable across various energy markets.

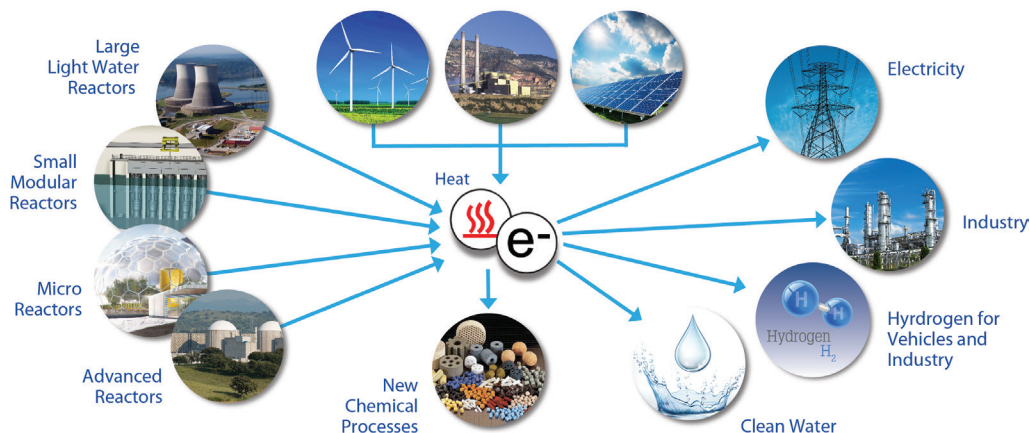
Integrated energy systems research is comprised of multiple focus areas working together to ensure technical feasibility, economic feasibility, and successful deployment. The integrated energy systems S&T initiative focuses on three primary areas of RD&D:

1. thermal systems, including transport and storage of heat generated from nuclear reactors and other sources,
2. electron systems, to manage an evolving electric grid and the electrification of the transportation system, and
3. energy and elements-to-molecules and materials systems to develop novel approaches to capture and convert energy to molecules and materials for direct use in industrial processes and the transportation sector.

Today Electricity-only focus

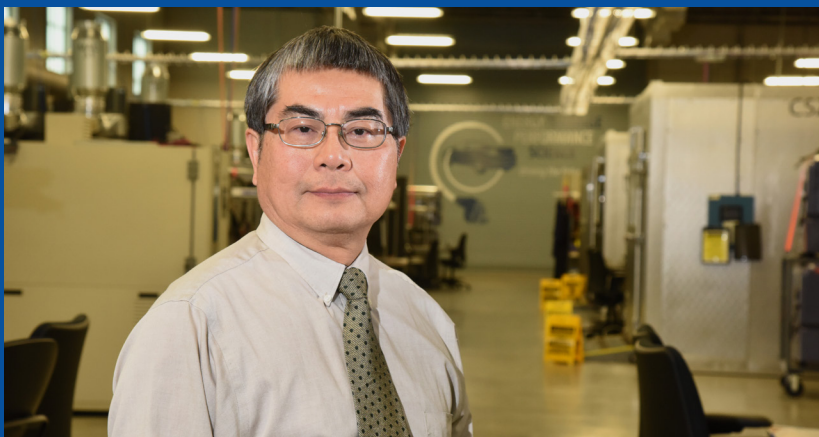


Potential Future Energy System Integrated grid system leverages contributions from nuclear fission beyond electricity



INL works to transform the existing energy paradigm. Currently, energy production is devoted to the grid. In the near term, INL researchers are partnering with industry to rethink how current generators can do more than just put electrons on the grid. In the long-term, INL is targeting S&T advances to design new systems, both small and large, to use heat, electricity, and radiation to drive many other processes.





Liaw's novel approach changes the entire product-development cycle with principle-based predictive models and failure analysis-based qualifications

LDRD SUCCESS STORY

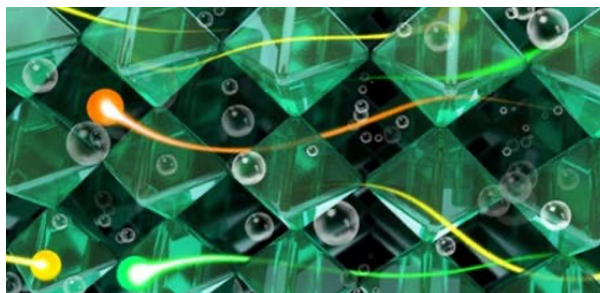
Boryann Liaw's team is developing an electrochemical analytic diagnosis technique that applies thermodynamic and kinetic principles to define the state of the energy system and analyze its performance characteristics through intensified data analytics. The results from the characterization and analysis could be used to qualify rechargeable lithium battery designs and products.



FY 19 IMPACT

Researchers at INL are addressing the challenge of how to store excess electricity for later use by developing a new electrode material for an electrochemical cell that can efficiently convert excess electricity and water into hydrogen. When demand for electricity increases, the electrochemical cell is reversible, converting hydrogen back into electricity for the grid. The hydrogen could also be used as fuel for heat, vehicles, or other applications.

A new triple-conducting protonic ceramic electrochemical cell allows passage of protons, oxygen ions and electrons to split water into H_2 and O_2 using electricity and to reversibly produce electricity when combining H_2 and O_2



INL upgraded its unique testing platform to support the demonstration and test of response characteristics of hydrogen production via high-temperature steam electrolysis

Large scale integrated energy testing infrastructure

As part of the thermal systems pillar, a fully integrated prototype system for high-temperature steam electrolysis was designed, installed, and is now being tested by INL for DOE. The system has been integrated with the digital real-time simulation and power emulators from the electron systems pillar, to emulate a diversity of load levels and types. This unique testing platform supports the demonstration and test of response characteristics of hydrogen production via steam electrolysis in a manner that can provide important grid services such as non-spinning power reserves and voltage or frequency regulation.



INL is part of DOE's tri-lab effort to enable new technologies in coordinated energy systems and tightly coupled hybrid energy systems

SECURE AND RESILIENT CYBER-PHYSICAL SYSTEMS

The cyber-physical systems integral to U.S. civilian and defense infrastructure depend upon transformational technological advancements that protect against the sophisticated capabilities of a global array of cyberattackers. To secure these systems, solutions must holistically integrate traditional information assurance methods with the controllability, reliability, and safety of physical process effects, as well as manage the interdependencies and resilience of complex, engineered systems. Through the secure and resilient cyber-physical systems S&T initiative, INL develops new cyber-informed engineering methods and technologies for automated controls that are validated systematically at scale. INL's holistic approach, which incorporates technology, people, and processes, addresses the nation's most critical control systems cybersecurity challenges to secure and defend vital U.S. cyber-physical systems.

INL's background in nuclear energy RD&D provides robust expertise in the evolution of sensors and controls in critical systems. This expertise extends to the design of real-world experiments to verify models, construction



INL cyber researchers and control systems engineers collaborate to provide a multidisciplinary approach to cyber vulnerability assessments

and operation of demonstration pilot plants to validate engineering principles at industry scale, and integration of complex systems and facilities into interdependent infrastructures. By blending the resulting scientific and operations expertise and capabilities, INL is uniquely capable of interdisciplinary threat analysis and consequence-based risk prioritization to enable groundbreaking RD&D of unclassified

and classified cyber-physical systems and the inherent embedded control systems integrated into power, communications, and defense systems. INL's efforts to advance secure and resilient cyber-physical systems center on three areas:

1. cyber-informed science and engineering,
2. all-hazard critical infrastructure, and
3. enduring control systems cybersecurity innovation.

DOE funded Enhanced Mitigations to Attacks on Power Systems test on transformer on the INL's Critical Infrastructure Test Range Complex





The outcomes of LeBlanc's research should create new risk-analysis methods that address the realities of cyberthreats in digital systems using the lessons from INL's growing CCE assessments and developing the robust sensitivity analysis of critical functions expected by the nuclear energy sector

LDRD SUCCESS STORY

Innovations across the domains of complex decision systems, cybersecurity, and human factors and reliability are enabling Katya LeBlanc to address fundamental issues in framing and appropriately quantifying risks in cyber-physical systems. LeBlanc's interdisciplinary research integrates the thought leadership of INL's National University Consortium, Center for Advanced Energy Studies, and INL researchers to innovate on these hard challenges



FY 19 IMPACT

In recognition of INL's long-standing Wireless Test Bed and wireless R&D capabilities, in FY 19 the Wireless Security Institute was established to focus on secure and resilient wireless R&D needed to protect the nation's critical infrastructure as it adopts 5G technologies and beyond, and create a collaborative forum for government agencies, labs, academic and industry researchers.



The Wireless Security Institute, established in 2019, focuses on secure and resilient wireless R&D



Providing assistance after a compromise is imperative to developing and sharing actionable information, but preventing a high-consequence attack is an even greater opportunity

Consequence-driven cyber-informed Engineering

Developed at INL, consequence-driven cyber-informed engineering (CCE) starts with the assumption that if a critical infrastructure system is targeted by a skilled and determined adversary, the targeted operation can and will be sabotaged.

The CCE approach provides critical infrastructure system owners, operators, vendors and manufacturers with a disciplined methodology to evaluate complex systems, determine what must be fully safeguarded, and apply proven engineering strategies to isolate and protect an industry's most critical assets.

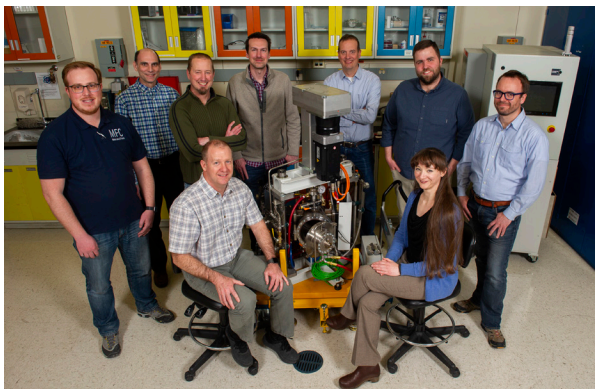


INL's critical infrastructure protection leadership enables the success of key national programs

SCIENTIFIC EXCELLENCE

INL's national and global scientific and technical leadership continued to grow in FY 19, with notable collaborations, growing capabilities, and expanding areas of expertise. INL remains at the forefront of resolving the world's most pressing energy and security challenges, today and into the future, because its passionate, talented, and dedicated staff are able to leverage the Laboratory's unique geography and world-class infrastructure and facilities.

LDRD is one of INL's tools to advance scientific excellence by supporting early-stage research that leads to distinctive INL capabilities and direct-funded projects. INL uses its LDRD investments to accelerate advanced nuclear energy RD&D, develop integrated fuel cycle solutions, accelerate advanced integrated energy systems, develop advanced materials and manufacturing processes for extreme environments, and improve the security and resilience of cyber-physical systems across critical infrastructure systems.

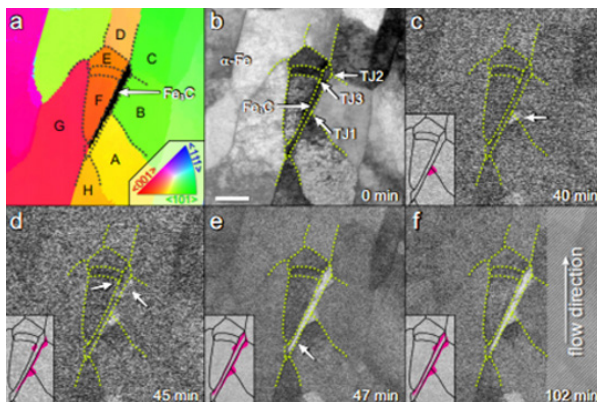


Top Left: Stephanie Pitts and her team are developing capabilities for advanced manufacturing Top Right: Ginger Wright helped grow an LDRD investment into the four-laboratory program Cyber Testing for Resilient Industrial Control Systems

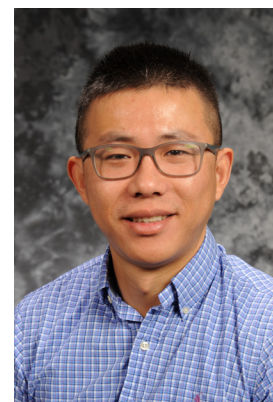


FY 19 IMPACTS

INL is growing its postdoc program, emphasizing quality recruiting and long-term retention, to strengthen its talent pipeline.



INL had 289 publications in FY 19, including an article in Nature on material science



Wei Wu is the inaugural recipient of INL's Outstanding Postdoc Award

4

INL-led R&D
100 Winners



A team from ATR won the 2019 INL Laboratory Director Award for Mission Enabling Operations Support for their work planning and coordinating the successful completion of three complex, mission-critical systems necessary for safe operation of the reactor

OPERATIONAL EXCELLENCE

INL's S&T strategy is built on a solid foundation of world-class RD&D infrastructure and facilities. INL facilities accommodate thousands of people daily, including employees, facility users, subcontractors, and others. Sitewide utilities and supporting infrastructure,

consisting primarily of roads, railroads, and power-distribution and communication systems, are maintained and operated to serve and connect campuses and facilities.

FY 19 IMPACTS

The July 2019 Sheep Fire was the largest in INL history, burning 112,107 acres. Emergency Management professionals and volunteer Emergency Response Organization staff initiated their response when alerted to the fire. Throughout on-scene fire response, behind-the-scenes crews at Site Emergency Control Centers, Idaho Falls' Emergency Operations Center and Joint Information Center provided around-the-clock support. This took the form of planning and decision-making, logistics support, and emergency public information for employees, media, and the public. Some operations were curtailed, and facilities were evacuated during the fire, but no buildings or structures burned, and no one was injured. Because INL provides technical expertise, guidance, training, communications support, and facilities for coordination and management of emergencies, and interfaces and maintains agreements with off-site agencies and communities to plan and prepare for mutual aid in disaster, INL was able to sustain operational excellence during the Sheep Fire.

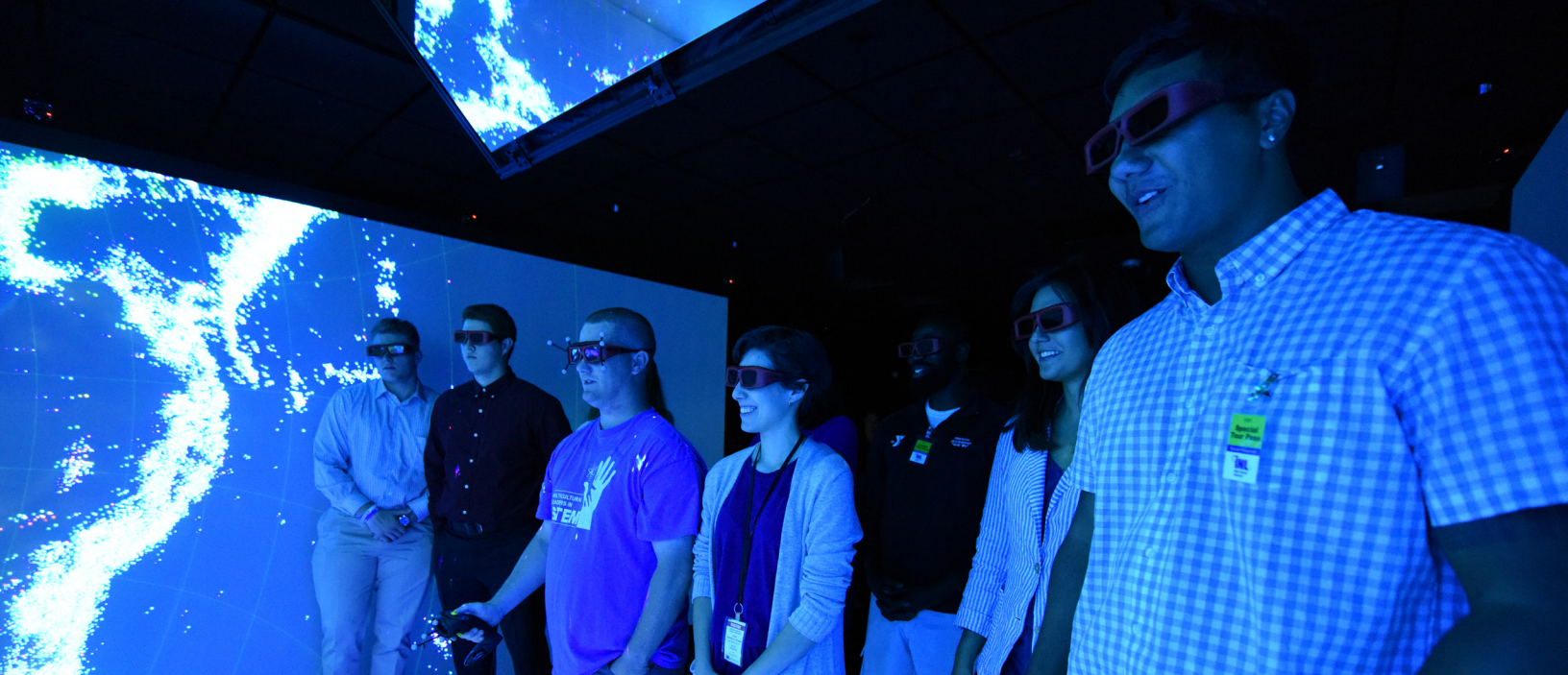
In October 2019, INL occupied two brand new, state-owned buildings at INL's Research and Education Campus: the Collaborative Computing Center (C3) and Cybercore Integration Center (CIC). INL and the state have signed memoranda of understanding establishing expectations on collaborations related to the new facilities. C3 and CIC are more than spaces for computers and people: they are a forward-thinking partnership with the state of Idaho that will pay dividends for Idaho residents, students, and the Laboratory far into the future.



INL is committed to a culture of safety. In FY 19, INL's Specific Manufacturing Capability reached over 1 million hours worked without a Day Away, Restricted or Transfer case – meeting this milestone for the ninth time in its 35-year history



C3, which houses the Sawtooth supercomputer, is INL's hub for modeling and simulation, connecting INL to Idaho's three research universities and collaborators around the world. CIC brings together the Laboratory's diverse portfolio of research focused on increasing the resiliency of the computer control systems operating the nation's critical infrastructures.



STEM tour of INL in partnership with Boise State University and the YMCA

STAKEHOLDER AND COMMUNITY EXCELLENCE

INL's relationship with its local, state, and regional partners is robust, growing, and mutually beneficial.

INL works closely with local constituents to address the needs and concerns of community stakeholders. INL provides DOE with appropriate and timely communication materials to ensure discussions with area Tribal groups are coordinated pertaining to the growth of the lab and new facilities. Additionally, INL provides outreach and communications to local constituents and stakeholders, providing information on lab growth initiatives.

INL's K-12 education programs create a strong STEM foundation for students with learning opportunities from preschool to high school, setting students on STEM education and career pathways. Initiatives include preschool STEM enrichment, coding and robotics program in the elementary grades, a pre-freshman engineering STEM camp for middle school students, and STEM and STEM-adjacent internships for high school students. For schools and teachers, INL offers a teacher scholarship and placement program for recruiting and retaining Shoshone Bannock tribal members as teachers in tribal schools.

Team INL is an employee-driven volunteer program supporting causes in the communities where INL employees live. INL employees have completed nearly 400 volunteer projects since 2005.

INL, on behalf of corporate funds provided by BEA, funds philanthropic projects from nonprofit agencies that focus on health and human services, disadvantaged youth, environmental projects, civic affairs, or culture and the arts. The priority of INL's community giving program is to give to organizations that support the basic needs of children and the underprivileged.

\$325k

awarded in scholarships
and K-12 STEM grants

More than

\$150M

spent with Idaho-based
companies

FY 19 IMPACTS

The State of Idaho and DOE recently signed supplemental agreements to the Idaho Settlement Agreement. These agreements facilitate the Lab's nuclear research needs and the long-term operations of ATR.

INDUSTRY PARTNERSHIPS

Technology transfer and industry partnerships are critical to accomplishing INL's mission, and the Lab is committed to enabling U.S. competitiveness through its RD&D. INL helps transfer technologies that advance energy assurance, national security, public benefit, and economic growth by effectively leveraging DOE's investments in INL research and facilities.

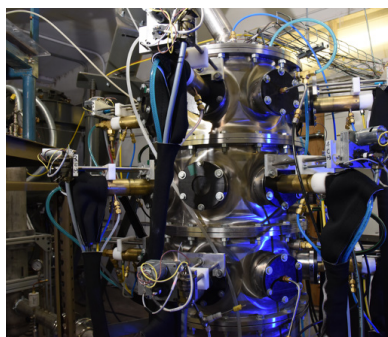
The INL-led NRIC is a national focal point for public-private partnership to spark innovation, and set in motion the experimentation, analysis, and demonstration to transition those innovations to market. NRIC focuses on cross-application and innovative collaborations across its core capabilities to advance private-sector efforts to prepare innovative nuclear technology for the market. INL continues to lead the Gateway for Accelerated Innovation in Nuclear (GAIN), which enables access for the advanced nuclear industry to the world-class DOE laboratory complex as well as providing the framework for a private-public partnership.



Integrated energy systems initiative nuclear power plant hydrogen production demonstration projects



Ashley Finan is the Director of NRIC and Nicholas Smith is the Deputy Director



FY 19 IMPACTS

INL won a 2019 Federal Laboratory Consortium National Award in the Technology Focus category for the successful transfer of small-scale waste-to-energy technologies to Cogent Energy Systems

More than
120
GAIN workshops
with industry

Active software
licenses for more than
492 users at **150**
institutions

UNIVERSITY PARTNERSHIPS

Through its university partnerships program, INL builds its talent pipeline while supporting RD&D aligned with the Laboratory's S&T initiatives. INL has forged strong relationships with colleges and universities, nationally and internationally, and actively encourages its scientists and engineers to collaborate with universities on research through joint appointments, hosting academic visitors and international researchers, and programs for faculty researchers and teaming teachers. INL attracts high-quality interns, graduate fellows, and postdoctoral researchers from across the United States and around the world.

INL cultivates two critical university consortiums by engaging with faculty nationally and regionally, under the National University Consortium and the Center for Advanced Energy Studies. The National University Consortium is comprised of five strategically aligned nuclear engineering departments at Massachusetts Institute of Technology, the Ohio State University, Oregon State University, North Carolina State University, and the University of New Mexico that contribute to defining the research needs in support of INL's clean energy initiatives. The Center for Advanced Energy Studies connects INL researchers and



2019 INL intern poster session



In its third year, the Center for Advanced Energy Studies Summer Visiting Faculty Program has grown to a network of over 75 INL and university researchers collaborating on proposals

resources with the University of Idaho, Idaho State University, Boise State University, and University of Wyoming to address regional clean energy research needs. Together, these

two collaborative frameworks complement INL capabilities to accomplish INL's mission and establish long-term relationships to educate the next generation of researchers.

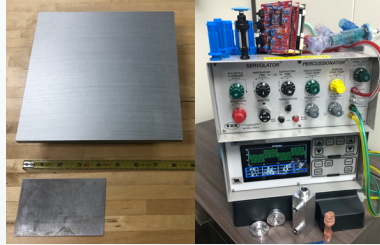
36
joint appointments from
17
institutions

470
interns from
117
institutions

SUSTAINING SCIENTIFIC, OPERATIONAL, AND STAKEHOLDER AND COMMUNITY EXCELLENCE DURING COVID-19

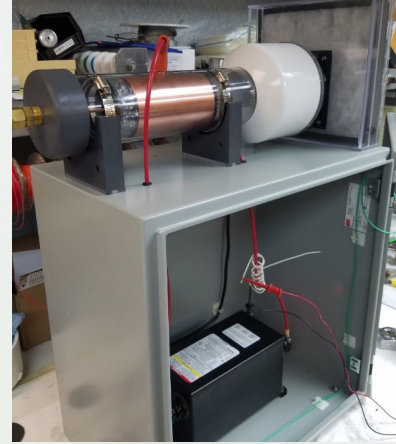
Since the beginning of the COVID-19 pandemic, INL's Senior Leadership Team has worked with local health officials, state government representatives, DOE, and other national laboratories to adjust and plan for working safely.

INL's primary focus is keeping staff safe while continuing essential operations. Laboratory leadership recognize that as challenging as this new normal may be, it does not change INL's obligation to continue doing a great job for its customers. The nation needs INL and the other DOE national laboratories, now more than ever. A Lab-wide look at work either conducted or highlighted during the COVID-19 pandemic shows that, under difficult and challenging circumstances, INL continues to execute world-class research.



INL has been leading a collaboration of 6 national laboratories with industry in the development of percussion air ventilator technologies that have enhanced manufacturing readiness level and are transformative of patient conditions in the fight against COVID-19

While continuing to execute its normal operations, INL has also brought to bear its world-class facilities, technical capabilities, and staff on problems specific to the COVID-19 pandemic.



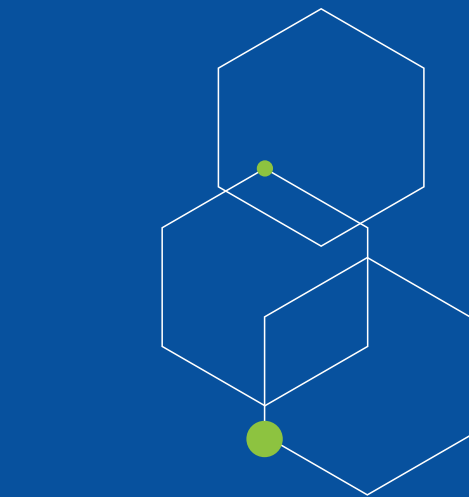
INL is using their expertise in advanced manufacturing to rapidly design and test a device to purify respired air on any existing ventilator, using electric fields to deactivate pathogens. INL staff propose to focus on the design of an advanced prototype auxiliary device to purify respired air on any existing ventilator, using electric fields to deactivate pathogens using high voltage low current discharge from a Tesla coil generator.

INL is part of the COVID-19 High Performance Computing Consortium with Sawtooth. Government, industry, and research institutions around the country are dedicating their high-performance computing resources gaining vital knowledge from modeling and simulation to support COVID-19 research.



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Idaho National Laboratory